Title: Distribution of Discharge from Liquid Manure Applicator Manifolds. NPB # 16-067

Investigator: Kapil Arora, Agricultural Engineering Field Specialist

Co- Investigator: Daniel Andersen, Assistant Professor

Institution: Iowa State University, Ames, IA

Date Submitted: December 1, 2017

Industry Summary: Each manifold tested had a different design and showed its performance capabilities and limitations in terms of the gallons per acre application rate it can adequately support. Results, thus, caution to appropriately select a manifold for applying manure so that the lowest possible coefficient of variation is achieved. Field testing also showed that it is helpful to eliminate any loops in the discharge hoses connected to manifold outlets as the hoses transverse over the tool-bar to the tool-bar points. Mounting the manifolds at the highest point possible should be considered, along with use of hose racks so the loops in the discharge hoses can be eliminated. Hose racks, if used, should be placed to achieve a continuous down gradient from the manifold outlet to the tool-bar point. Any vents provided on the manifold outlets need to be clean and functioning so they allow all the leftover liquid in the hoses to discharge freely and do not allow air-locks to develop within the hoses or in the manifold chamber. The coefficient of variation can be improved with increase of drive speed as it will increase the flow rate (gpm) through the manifold chamber. This option should be considered, where feasible, when trying to improve distribution. The results did not show a direct correlation in how the CV changed with increase in slopes studied, although, certain manifolds showed increased variability with increase in slope. The results presented in this report should be used with caution when dealing with distribution of liquid manures with higher viscosities.

Keywords: application technology, coefficient of variation, discharge, distribution, manifolds, tank-mounted, liquid, manure, manure management, manure spreaders, nutrient management, uniformity.

Scientific Abstract: Uniformity of liquid manure application across the tool-bar points is important to ensure proper nutrient supply for crop growth, to maintain producer confidence in nutrient availability, and for addressing water quality concerns. To date, no research has been performed at field-scale to determine the variability of liquid distribution across the tool-bar points, transverse to the direction of travel. In this project, seven commercially available, tank-mounted manifolds and three dragline mounted manifolds used for liquid manure application were tested for coefficient of variation. Testing was performed using water and coefficients of variation were determined for application rates ranging from 2,000 gallons per acre to 6,000 gallons per acre by setting the manifolds under field conditions and using manufacturer specifications for operation. The tests were performed under three different slope conditions of 0, 3, and 6 percent to simulate cross-slope manure application. Coefficient of variation, as measured across the tool-bar, was less than 20 percent for five of the ten manifolds tested for the five application rates for all three-slope settings. Two manifolds tested had coefficient of variation less than 10 percent for all of the test settings. On the opposite end, coefficient of variation for one of the manifolds exceeded 100 percent. Results of the testing indicate that caution should be exercised to select the appropriate manifold when applying manure such that the lowest possible coefficient of variation is achieved.

Introduction: Liquid manure application in Iowa typically takes place in fall after harvest in preparation for the following crop year. Manure is either transported and land applied with tank wagons and/or directly pumped and land applied using a dragline system. Application rate, gallons per acre, is typically controlled by flow control actuators operated by on-board rate controllers which co-process the drive speed, tool-bar width, and the flow meter reading with the operator input of application rate. This system ensures that the desired application rate is achieved for manure application. The manure is supplied to a distribution manifold after it passes through the flow control valve. The manifold is responsible for distribution of the liquid manure to different points on the tool-bar.

Manifolds can be mounted on tank wagon tool-bars or dragline tool-bars. A distribution manifold, typically has an inlet through which it receives the manure supply, a chamber, and several outlets through which the manure is distributed to the tool-bar points. Different manifolds have different configurations in terms of the inlet size & location, chamber size, and the size, number, and location of outlets. Each manifold has its own performance capabilities in terms of how uniformly it distributes liquid manure and the application rate it can effectively manage.

Calibrating the application rate in terms of gallons per acre (gpa) does not specify how uniformly the manure is being distributed within the tool-bar swath. This calibration, which can be achieved with the area-volume method, is essential to ensure the manifold chamber is pressurized to the extent possible by receiving the appropriate flow rate in gallons per minute (gpm). The area-volume calibration of liquid manure tank wagons is explained in detail in the Iowa State University Extension & Outreach Publication AE 3601 (a revised version of PM 1948). Application rate with draglines can be calibrated with a similar method using the area measurement with the flow rate measurements from the flow meter. Such calibration, however, does not characterize any variability that may exist between the amount of liquid manure discharged to different points on the tool-bar. A calibration of a specific application rate may still be achieved while a few tool-bar points may not be applying any manure while other tool-bar points may be applying twice or three times the application rate.

Variability in the manifold discharge can be significant when the manifold chamber is not pressurized under low application rate conditions. Liquid swine finishing manures are beginning to test relatively high values of total nitrogen per 1,000 gallons. Secondly, the Maximum Return to Nitrogen Rate (MRTN; ISUEO, 2016 and Sawyer et al., 2006) Calculator is showing lower total nitrogen need for a corn crop in corn-soybean rotation than was previously calculated with the yield goal method. High manure nitrogen test values coupled with lower total nitrogen need is resulting in manure application rates to be lower than what they have been in the past for liquid swine finishing manure.

The MRTN Calculator, using a nitrogen fertilizer price to corn price ratio of 0.08, calculates a 141 lb/ac nitrogen rate for the corn crop under a corn-soybean rotation in Iowa. The profitable nitrogen rate range is calculated as 128 lb/ac to 154 lb/ac, which is ±10 percent of the 141 lb/ac rate. Corn yield at this nitrogen application rate is 99 percent of the maximum yield. High nitrogen testing swine manure further reduces the application rate, especially if split applications are used to supply the 141 lb/ac nitrogen application rate. The previously mentioned nitrogen test numbers of 70 pounds per 1,000 gallons can supply the 141 lb/ac nitrogen when applied at a rate of 2,000 gpa, assuming 100 percent nitrogen first-year availability. A 50- 50 split on nitrogen rate will mean a liquid swine manure application rate of 1,000 gpa. Use of such low liquid swine manure application rates creates the necessity to test the liquid manure distribution manifolds and verify the coefficient of variation at different application rates. The calculator determines the desired nitrogen to within 10 percent of the target nitrogen needed. It is, therefore, desirable to achieve a coefficient of variation of 10 percent or lower for liquid manure distribution manifolds when targeting any application rate.

Low application rates can influence how variable a manifold performs in its discharge to the different tool-bar points. High variability can lead a producer to believe that manure nutrients are not available to match the crop needs. This can lead a producer to commit to an expenditure of supplementing additional nutrients. Excessive nutrients on the field can lead to water quality issues as related to surface water and sub-surface drainage water. It is, therefore, essential to verify hydraulic distribution of liquid manure applicator manifolds across the tool-bar swath.

Objectives: The objectives of this study were to

Determine the uniformity of distribution across the outlets of six different manifolds (tank mounted and drag line mounted) from two different manufacturers comprising of 8 to 24 outlets for application rates ranging from 1,000 gallons per acre to 6,000 gallons per acre.
Determine any changes in the uniformity of distribution calculated in Objective 1 for three different slopes of 0, 3, and 6 percent.
Compare performance data between the tank mounted and drag line mounted manifolds for coefficient of variation.

Materials & Methods: The Coefficient of Variation (CV) is used by American Society of Agricultural & Biological Engineers (ASABE) to measure uniformity of pesticide sprayers. The coefficient of variation methodology was also used by Hanna et al. (2004) to test the uniformity of spreaders for dry manure. The same CV can be used to determine the distribution of liquid from different outlets of a manure application manifold as it is a better statistical measure than the mean absolute error. Absolute error only measures the difference between the average outlet discharge and measured outlet discharge. The coefficient of variation measures the variation across the different tool-bar points as the manifold outlets are connected to these points with discharge hoses. This measurement is a measurement of variation in the direction transverse to the direction of travel. The coefficient of variation across the manifold outlets can be defined by Equations 1, 2, and 3 as:

$$CV = 100 * (\sigma/\bar{Q}) \quad (1)$$

$$\sigma = \sqrt{\frac{\Sigma(Qi-\bar{Q})^2}{(n-1)}} \quad (2)$$

$$\bar{Q} = \frac{\Sigma Qi}{n} \quad (3)$$

where CV is the coefficient of variation, σ is the standard deviation, $\bar{Q}$ is the arithmetic average flow rate from all outlets, Q_i is the flow rate of the i th outlet, and n is the total number of manifold outlets. When using Equation 1, low CV refers to better uniformity.

Discharge from tool-bar points can be collected for a given time period and measured for variability. A coefficient of variation can then be calculated to ascertain the variability across the tool-bar swath. Using this concept, seven tank-mounted and three dragline manifolds were tested in Summer of 2015, 2016, and 2017 using water. Discharge hoses were connected together to a wooden beam to allow for simultaneous collection and stoppage (Figure 1). Water from the discharge hoses was collected for 15 seconds in fifty-five gallon straight wall drums. Height of the water collected in the

Figure 1: Fifty-five gallon drums arranged underneath the discharge hoses to compare variability across the tool-bar swath.

drums was measured and converted into gallons using a calibration curve. Using the pre-determined drive speed and the tool-bar swath, the amount of water collected was converted to the application rate (gpa). Manifolds were tested, using tractor control settings, for application rates ranging from 2,000 gpa to 6,000 gpa. In certain cases, a lower application rate of 1,000 gpa was also tested. Manifolds were tested under three different slope settings of 0, 3, and 6% to simulate the tool-bar travel across the slope in a field.

Seven different tank-mounted and three different dragline-mounted manure distribution manifolds were tested in this study (Figure 2). Manifold 1 was a crescent-moon shaped manifold with seven un-equally spaced outlets with manure entering at an angle to the manifold orientation. Manifold 2 was a circular manifold with manure entering from the bottom and had 12, relatively equally-spaced outlets on the circumference. This manifold had outlet blocking plates mounted on a hydraulic motor which were capable of restricting the outlet area. Manifold 3 was similar to Manifold 2 but only had 8 outlets. In case of this manifold, the eight outlets were along the 240-degrees circumference of the manifold. The remaining circumference (120 degrees), facing the tank, had no outlet as can be seen in Figure 2. In case of the fourth manifold, the manure entered from the bottom and six equally spaced inverted outlets were mounted on the top of the manifold. This manifold was mounted on top of the end wall of the tank whereas all other manifolds were mounted on top of the tool-bar. Manifold 5 had eight equally spaced outlets with manure entering the manifold at an angle on top of a large drum. Sixth manifold had 20 outlets where 12 outlets were coupled by directing the flow from one to the other as per manufacturer directions. In case of this manifold, 10 outlets were facing one side where as the other 10 outlets were directly opposite to them (Figure 2). Manure entered the manifold from the bottom in this case. Thus, only eight manifold outlets were allowed to discharge during

Manifold 1 – Crescent Moon

Manifold 2 – Outlets on Full Circumference

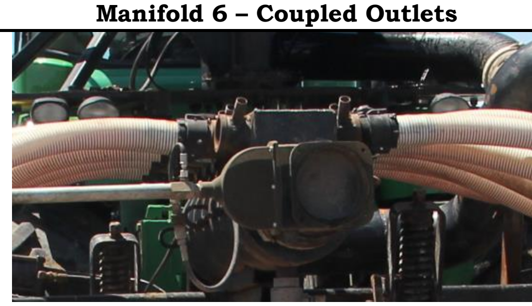
Manifold 3 - Outlets on 2/3 Circumference

Manifold 4 – Inverted Outlets

Manifold 5 – Outlets on Large Drum

Manifold 6 – Coupled Outlets

Manifold 7 – 24-outlets on Circumference



Manifold 8 – Rectangular Box on a cylindrical drum

Manifold 9 – 14-outlet circular manifold

Manifold 10 – Weighted & Flapped Outlets

Figure 2: Seven different tank-mounted and three different dragline-mounted manure application manifolds tested during the experiment in 2015.

its testing. Manifold 7 was a dragline manifold with 24 outlets on the circumference on the manifold. These outlets were offset in height to accommodate all 24 outlets on the circumference. Similar to Manifold 2, this manifold also had outlet blocking plates capable of restricting the outlet area. Manifold 8 had a rectangular box mounted on top a circular drum. Manure entered into this circular drum from one end, then rose up in the drum, and was discharged out from the outlets mounted on the rectangular box. Manifold 9 had 14 outlets mounted on the circumference of the circular drum where the manure entered from the bottom. There were shearing heads mounted on a hydraulic motor which rotated inside the drum to keep the outlets free of any debris. Manifold 10 had outlets mounted at the bottom of the rectangular box where manure entered from the side on the top (Figure 2). Once the manure entered the box, it passed through a screen before dropping to the bottom of the box and rising up to the outlets. The outlets were baffled with flaps mounted on a single shaft for either side of the outlets. Each shaft had counter weights mounted on the end of the shaft such that the manure flow was baffled by the weight of the counter weights. Measurements made in this experiment for all manifolds represent the coefficient of variation across the tool-bar points i.e. in a direction transverse to the direction of travel.

Results: Manifold 1 (crescent moon shaped) had coefficient of variation (CV) in excess of 10% for all test application rates for all three slope settings (Figure 3A). The red line in Figure 3 for different manifolds corresponds to the 10% variability as discussed in the introduction. As the application rate changed from 3,000 gpa to 6,000 gpa, the CV increased to over 50% for all three slope settings. At 1,000 gpa and 2,000 gpa, the variation in the water collected in the drums was significant. With the increase in slope, the CV increased for all test rates except 1,000 gpa, where it decreased first and then increased. Field observations made during testing showed greater depths recorded in the drum towards the upslope end of the tool-bar under 3% and 6% slope setting. These results indicate that due to momentum of the fluid entering the manifold, eddies or vortexes can develop within the manifold leading to variable results. The down-slope end of the manifold acts as a splash-plate re-directing the fluid towards the up-slope end, thus, causing the CV to increase with increasing slope setting. Results indicate that additional tests with this manifold are needed to find the application rate where the CV is below 10%. Alternatively, the manifold needs major adjustment to find a way to get variability less than 10%.

Coefficient of variation for Manifold 2 (with outlets on full circumference) was slightly above 10% at the zero percent slope setting for the 6,000 gpa test application rate (Figure 3B). The CV improved and dropped below 10% with increase in slope from 0% to 3 % and then again from 3% to 6%. This was the case for 3,000 gpa to 6,000 gpa test application rate. At 2,000 gpa test rate, the CV increased to 20% for the zero percent slope setting, however, the trend of lower CV with increasing slope was true for this test rate. At 1,000 gpa, the CV was less than 10%, however, an increase from the 0% to 3% slope was observed followed by relatively no change in CV when the slope increased from 3% to 6%. The main reason for lower than 10% CV is that the manifold has a small cavity it uses to distribute the flow amongst the outlets on its circumference. Secondly, the blocking plates mounted on a rotating motor, keep three or more outlets blocked leading to a reduced outlet area to inlet area ratio. This outlet area to inlet area ratio would be higher for this manifold if the blocking plates were not installed. This will also be true for manifolds without any blocking plates.

Manifold 3 was similar in design to Manifold 2, except that it had only eight outlets which were evenly spaced on 2/3 of the circumference of the manifold (Figure 2). The

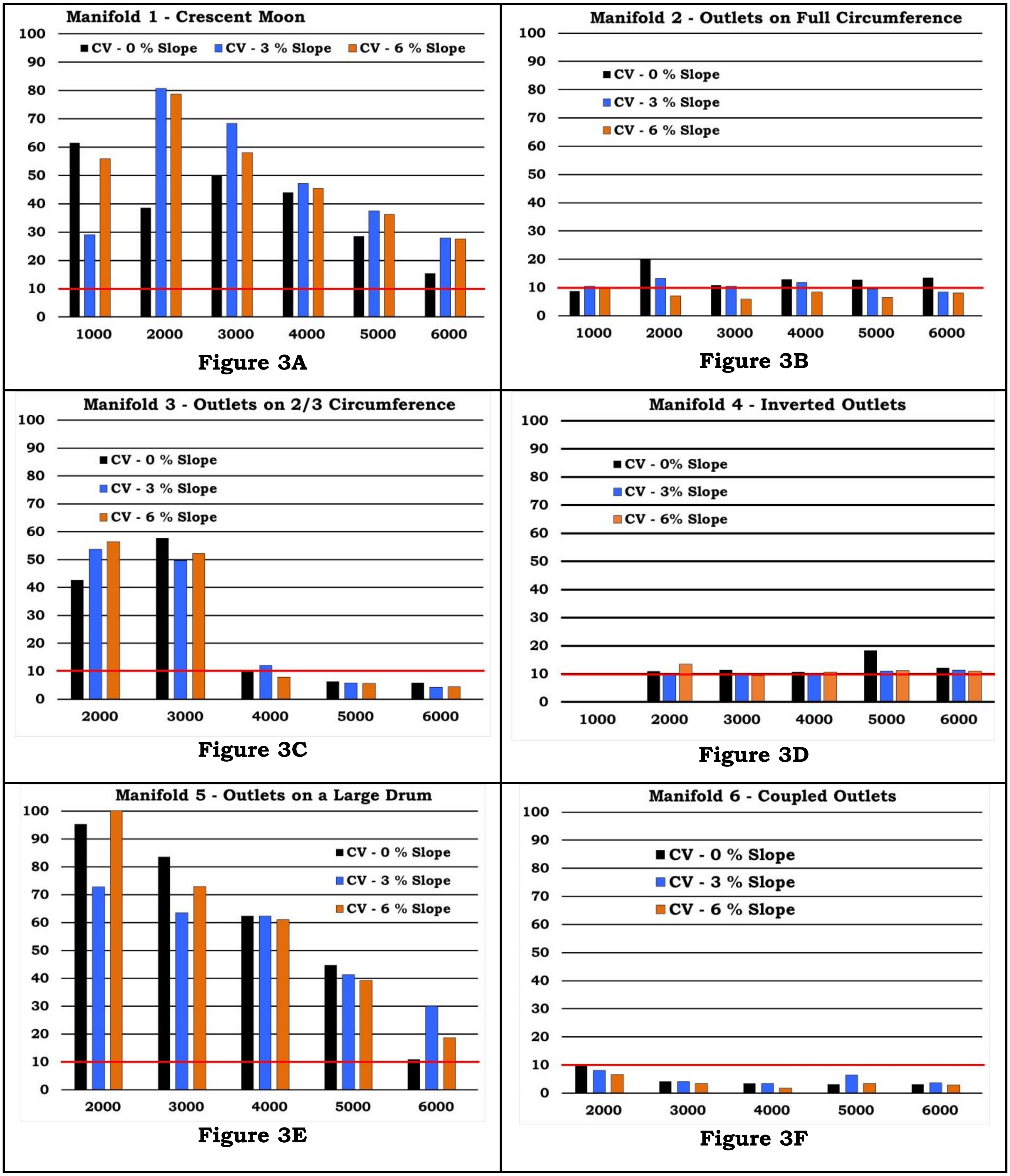


Figure 3. Coefficient of Variation (CV) for different manifolds studied for the different application rates for three different slope settings. In the sub-plots above, CV (percent) is plotted on the y-axis and the application rate in gallons per acre is plotted on the x-axis. Legend is the same for all six sub-plots.

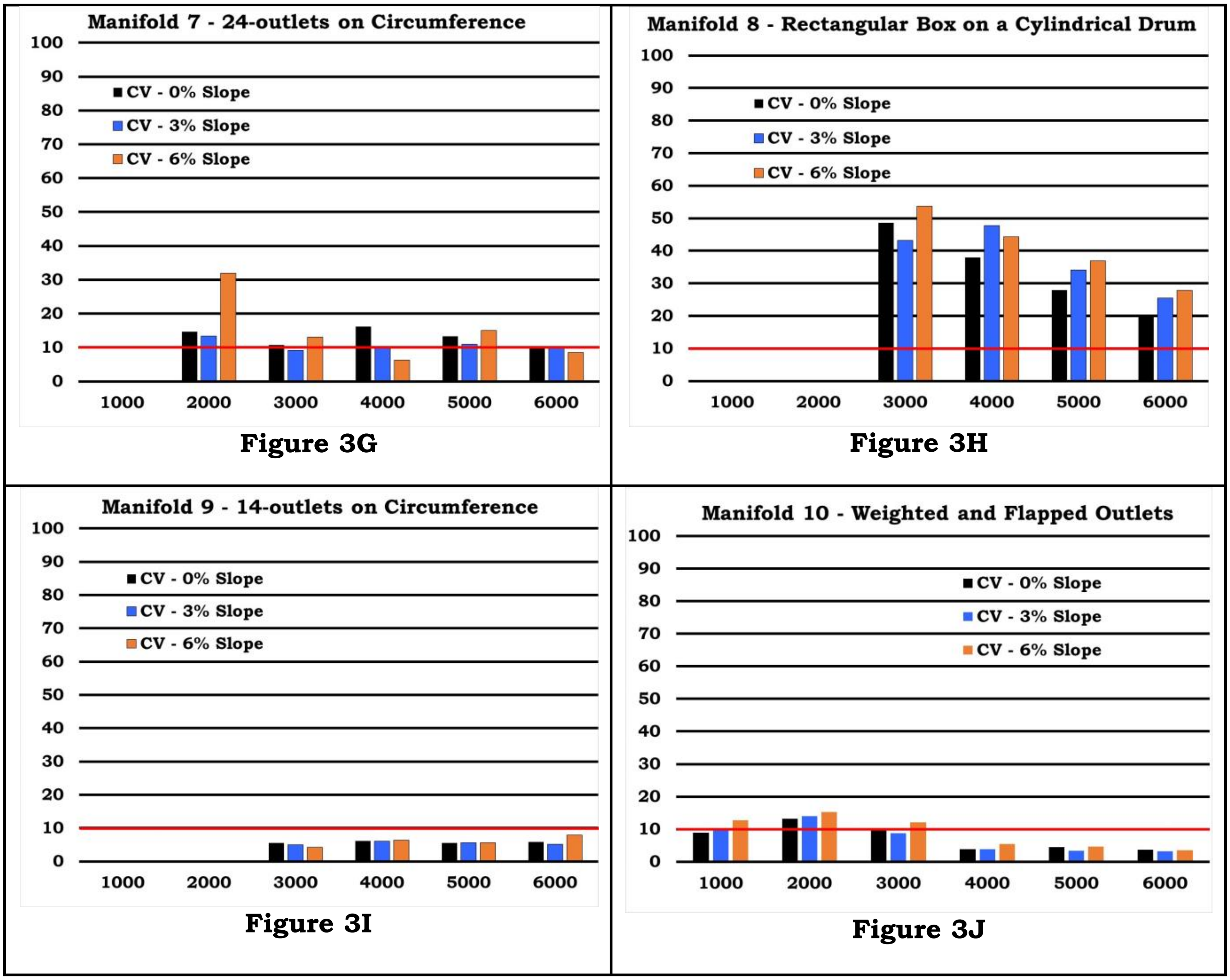


Figure 3G **Figure 3H** **Figure 3I** **Figure 3J**

Figure 3 (continued). Coefficient of Variation (CV) for different manifolds studied for the different target test application rates for three different slope settings. In the sub-plots above, CV (percent) is plotted on the y-axis and the target test application rate in gallons per acre is plotted on the x-axis. Legend is the same for all four sub-plots.

coefficient of variation was below 10% for test rates of 4,000, 5,000, and 6,000 gpa for all three slope settings (Figure 3C). The coefficient of variation increased to 40% and above for 2,000 gpa and 3,000 gpa test rates. The less number of outlets reduced the tool-bar width which in turn reduced the flow rate (gallons per minute) being pumped through the manifold. Secondly, hose loops were observed in the discharge hoses as the hoses strung from the manifold outlets to the tool-bar points. These loops can have liquid left in them from previous runs which does not empty out by gravity once the pump is shut off. It appears that this liquid can produce enough back pressure on the un-pressurized outlets of the manifold under low flow conditions. This back pressure can behave as a pressure plug and not allow an outlet to discharge resulting in uneven distribution of liquid amongst the outlets. One important point is that this manifold had CV less than 10% at higher application rates. From a practical standpoint, this means that as we get to lower application rates, the travel speed is increased as much as practical to keep flow rate (gallons per minute) through the manifold comparable to the higher application rates.

Manifold 4 (inverted outlets) had the largest setup height as it was mounted towards the top of the back-end of the tank wagon. In the initial test completed in 2015, the outlet hoses were strung straight down to the drums and there were no loops in these hoses. Secondly, there was no tool-bar attached to this wagon as it was still under construction. The coefficient of variation was less than 10% for the three slope setting for test rates of 2,000 gpa to 6,000 gpa. In this manifold, the inlet is at the bottom of the manifold and outlets are baffled. As the outlet discharge hoses were not strung over the tool-bar in this test, a re-test was conducted in 2016 to measure the CV with the tool-bar attached. This re-test presented comparable data to see the effect of hose loops. Results of the 2016 test for coefficient of variation are shown in Figure 3D. Coefficient of Variation in this test was about 10% for application rates of 2,000 gpa to 6,000 gpa. In comparison to the 2015 test, the CV increased from an average of 5% to an average of 11%. These results indicate that reduction in hose loops can help to achieve better performance from the manifold.

Manifold 5 (outlets on large drum) had coefficient of variation results over 10% for all application rates at all three test settings (Figure 3E). This manifold was impacted the most during testing with hose loops. At the lower test rates, the outer two outlets on either side of the tool-bar did not flow at all. In addition to four outlets not discharging, the remaining four outlets in the center of the tool-bar, had variable outflow. At the 2,000 gpa under 6% slope setting, the CV exceeded 100%. Testing at 1,000 gpa test rate could not be performed due to the inability of the tractor controls to produce a stable flow through the flow meter. It is, however, clear that this lower rate would have test with CV equal to or greater than the CV for the 2,000 gpa test rate. Testing of Manifold 5 at applications rates over 6,000 gpa is required to see where the CV may fall below the 10% threshold. The current experimental design cannot be used as the 55-gallon drums will be too small for collecting outflow for 15 seconds at higher application rates. Such testing will require larger volume drums or tanks which can handle greater discharge amounts from the outlets than the amounts discharged in this experiment.

Manifold 6 (coupled outlets) produced test results with coefficient of variation less than 10% for all three slope settings for 2,000 gpa to 6,000 gpa test rates (Figure 3F). This manifold had outlets 2-inch in diameter whereas manifolds 1 through 5 had outlets 3-inch in diameter. This manifold also had blocking plates mounted within the manifold to restrict certain outlets from discharging at any given time. As these plates revolved within the manifold, the outlets restricted changed with time. Smaller outlet area combined with outlet blocking helped the outflow from this manifold to be relatively uniform across the eight outlets tested.

Manifold 7 (24-outlets on circumference) was mounted on top of a dragline when testing was conducted. Testing showed that the coefficient of variation ranged from 6% to 16% for all three slope settings and application rates with one exception (Figure 3G). Application rate of 2,000 gpa at 6% showed a CV of 32%. This manifold had blocking plates mounted in the rotating head to restrict the outlets from discharging at any one time. At low flow rates, these plates did not appear to keep the outlets restricted enough to achieve full capacity in the manifold chamber. As such, tilting of the manifold in one direction can potentially produce a higher CV when dealing with wide tool-bars.

Manifold 8 (rectangular box on a cylindrical drum) was not tested for 1,000 gpa or 2,000 gpa per the manufacturer recommendations. Testing was completed for 3,000 gpa to 6,000 gpa in 1,000 gpa increments and the CV results are shown in Figure 3H. Coefficient of Variation was higher than 10% for all three slope settings for the four application rates tested, however, the trend was lower CV with increased rate. Under low flow conditions, this manifold is not best suited to achieve good uniformity and can potentially be more effective under higher rates.

Manifold 9 test results showed a coefficient of variation with an average of 5% for all three slope settings and for the four application rates tested (Figure 3I). The coefficient of variation ranged from 4% to 6% for this 14-outlet circular manifold mounted on a dragline. This manifold performed relatively more uniformly in comparison to other manifolds tested.

Manifold 10 (weighted and flapped outlets) showed a coefficient of variation ranging from 8% to 15% for application rates of 1,000 gpa to 3,000 gpa, whereas the CV ranged from 3% to 5% for application rates of 4,000 gpa to 6,000 gpa. The manifold had ten outlets but two were plugged during testing as the discharge hoses were too short to reach the test drums.

Secondly, testing with eight outlets made it comparable with other manifolds tested with eight outlets. Similar to other manifolds, this manifold also showed an improved uniformity with increase in application rate. Its performance was relatively better than manifolds 1, 3, and 5 for low application rates of 1,000 gpa to 3,000 gpa.

The different manifolds tested in this experiment had different shapes along with different number and size of outlets, and different location of the inlet. As such, each manifold is independent for its performance capabilities in terms of the coefficient of variation. Each manifold is potentially capable of achieving CV of 10% or less depending upon the flow rate (gallons per minute) passing through it. Certain manifolds, by design, can achieve CV of 10% or less at lower application rates where as certain other manifolds achieve it at higher application rates. Results of this applied research indicate that lower application rates with CV of less than 10% are feasible with appropriate choice of manure distribution manifolds. This can help producers to land apply liquid swine manure effectively, and can partly help in answering the question of manure nitrogen availability. Better distribution of manure nitrogen can further help to reduce the need of land applying supplemental nitrogen as side dressing in spring, thus, resulting in cost savings as well as water quality benefits.

Discussion: Coefficient of variation, calculated for the average application rate as measured across the tool-bar, was less than 20 percent for five of the manifolds tested, for the five application rates and all three slope settings. Two of the ten manifolds tested with a coefficient of variation less than 10 percent for all of the corresponding test settings. On the opposite end of testing results, coefficient of variation for one of the manifolds exceeded 100 percent.

Observations made during manifold testing showed that the momentum of the fluid entering the manifold can cause eddies or vortexes to develop within the chamber leading to variable results under low application rates. As the manifold chamber is not pressurized at low application rates, different parts of the chamber can act as a splash-plate redirecting the fluid towards different outlets, thus, causing the CV to increase.

Certain manifolds had a smaller manifold chamber in comparison to other manifolds. These manifolds also had blocking plates mounted on a rotating motor in order to keep three or more outlets blocked leading to a reduced inlet-to-outlet area ratio. Smaller manifold chambers, along with reduced outlet-to-inlet area ratio, appeared to help achieve lower CV.

Manifold 1, 5, and 8 test results showed significantly higher coefficient of variation (Figure 3) at lower application rates. Increasing the application rate improved the CV, but was never less than 10 percent. These results indicate that it is not feasible to achieve low CV with these three manifolds for the application rates tested in this experiment. As such, these manifolds are better suited for higher application rates as the testing trend showed a reduction in CV with increased application rate.

Results of the testing indicate that caution should be exercised when selecting the appropriate manifold for applying manure so the lowest possible coefficient of variation is achieved. Each of the manifolds tested showed its performance capabilities and limitations in terms of the gallons per acre application rate it can adequately support. The results did not show a direct correlation in how the CV changed with increase in slope.

Loops in the discharge hoses were observed during the majority of the manifold testing. These loops existed as the discharge hoses strung from the manifold outlets to the tool-bar points. These sags can have liquid left in them from previous runs which does not empty out by gravity once the pump is shut off. This liquid can produce enough back pressure on the un-pressurized outlet of the manifold under low flow conditions to behave as a pressure plug and not allow an outlet to discharge, resulting in uneven distribution of liquid among the outlets. Mounting the manifold at the highest possible location can provide adequate elevation difference to minimize hose loops. Hose racks can be used to help with removal of hose loops. Hose racks, if used, should be so mounted that there is a continuous down gradient from the manifold outlet to the tool-bar point. To aid with hoses emptying out between runs, certain manifolds have air vents mounted on the outlets to allow air to enter the manifold chamber or hoses and avoid air-locks from developing. Testing of manifolds showed that these air vents must be functioning properly and be free of all debris or they can cause the CV to be significantly variable. Results for different manifolds shown in Figure 3 were obtained by eliminating all plugged air vents.

Secondary causes for lower uniformity across the manifold discharge outlets can be the roll (slope) of the ground across which the manure applicator is operated in the field while performing land application. The slope of the ground can cause the manifolds to be in an inclined position which can potentially lead to a non-uniform discharge across the manifold outlets. Similar issues can be anticipated when the applicator is driven up or down hills causing the manifold to be inclined due to the pitch of the ground. Any loss of uniformity due to the pitch of the ground is expected to be similar to the roll of the ground for the same angle of inclination involved for symmetrically shaped manifolds. Testing results showed no definite correlation between the change in slope and the corresponding coefficient of variation over the range of slopes studied. In the case of certain manifolds, the CV increased with increase in slope whereas the converse was true for other manifolds. The shape of the manifold and the orientation of the outlets with respect to the inlets had a greater impact on how the manifold performed with increase in slope. It is expected that at larger slopes exceeding 6%, the manifold may be tilted enough and the up-slope end of the tool-bar is raised enough that a continuous down gradient may not exist from the manifold outlet to the tool-bar point. In such cases, it may help to have multiple manifolds on the same tool-bar which are mounted higher to achieve down gradient.

The coefficient of variation can be improved with increase of drive speed as it will increase the flow rate (gpm) through the manifold chamber. This option should be considered, where feasible, when trying to improve distribution. Lastly, the results presented in this report should be used with caution when dealing with distribution of liquid manures with higher viscosities.

References:

Arora, K., Kohl, K., Andersen, D. S., Licht, M. A., and DeJong, J. (2016). Calibrating Liquid Manure Tank Applicators. Extension Publication AE 3601A, Iowa State University Extension and Outreach, Ames, IA 50011. Available online at **https://store.extension.iastate.edu/product/6499**

Arora, K. and Andersen, D. S. (2016). Distribution of Liquid Manure Tank Application. Extension Publication AE 3600, Iowa State University Extension and Outreach, Ames, IA 50011. Available online at **https://store.extension.iastate.edu/product/14891**

Arora, K. & Andersen, D. S. (2016). Coefficient of Variation of Discharge from Liquid Manure Applicator Distribution Manifolds. Paper presented at the ASABE Annual International Meeting, Disney's Coronado Springs Convention Center, Orlando, Florida. 17 - 20 July, 2016. ASABE meeting paper number 162460271. (doi: 10.13031/aim.20162460271).

Hanna, H. M., T. L. Richard, and Quick, G. R. (2004). Optimizing Solid Manure Application by Improving Distribution. Pp 55-58. Leopold Center Progress Report Volume 13. Leopold Center for Sustainable Agriculture, Iowa State University, Ames, Iowa. Leopold Center Completed Grant Reports. Available online at **http://lib.dr.iastate.edu/leopold_grantreports/219** and viewed: June 9, 2016.

Iowa State University Extension and Outreach (2016). MRTN On-line Calculator. Iowa State University Extension and Outreach, Ames, Iowa. Available online at **http://cnrc.agron.iastate.edu/nRate.aspx** and viewed: June 9, 2016.

Sawyer, J., Nafziger, E., Randall, G., Bundy, L., Rehm, G., and Joern, B. (2006). Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn. PM 2015. Iowa State University Extension and Outreach, Ames, Iowa 50011. Available on-line at **https://store.extension.iastate.edu/Product/12240** and viewed: June 9, 2016.

Acknowledgements: This project has been funded in part by the National Pork Board. The authors would like to thank the industry partners for making their equipment available to test the manifolds and also acknowledge their in-kind contributions for manpower, fuel, and water for without which this project would not have been accomplished. Authors also thank reviewers, Mark Hanna, agricultural engineering specialist with ISU Extension and Outreach; Mark Garrison, environmental engineer, with United States Department of Agriculture – Natural Resource Conservation Service; and Reza Khosravi, environmental engineer senior, Animal Feeding Operations, with Iowa Department of Natural Resources for their valuable insights.